PENNSTATE ARL

iMAST

Institute for Manufacturing and Sustainment Technologies

A U.S. Navy Manufacturing Technology Center of Excellence

QUARTERLY

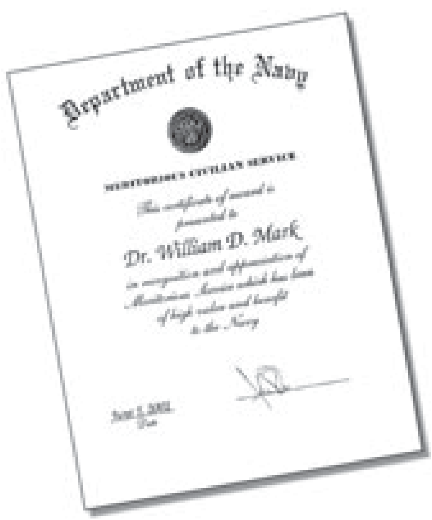
2001 No.2

iMAST Senior Scientist Honored

Exercising superb leadership and technical expertise, Dr. William Mark, a Senior Scientist within ARL's Drivetrain Technology Center (DTC), was recently awarded the Navy Meritorious Civilian Service Award for his unique and outstanding performance while serving as lead analyst and designer for a mechanical modification that resulted in improved operational submarine performance. This award is the second highest civilian award given by the Navy. Recipients who are nominated for the award must also have an established pattern of excellence before they can be considered.

Dr. Mark's success was spawned as a result of his U.S. Navy ManTech efforts under an iMAST project titled: "Gear Metrology and Performance Prediction" (project S0728). Cited for his ability to innovatively apply his exceptional technical expertise, Rear Admiral J. R. Davis, USN, Program Executive Officer for Submarines, also acknowledged the difficult conditions confronting Dr. Mark during the course of his effort. His ability to innovate under these trying conditions was cited by the admiral as a noteworthy achievement in its own right. Admiral Davis further notes that Dr. Mark's work served the best interests of the Naval Sea Systems Command and the U.S. Navy.

Providing a direct solution to a critical fleet issue, Dr. Mark employed leading-edge gear technology skills to assist TEAM SUBMARINE in innovative measures which met significant challenges within the U.S. Navy submarine community.



Dr. Mark, who joined ARL in 1992, currently heads up the metrology and performance prediction thrust within ARL's Drivetrain Technology Center. In this capacity, he is responsible for developing fundamental theory and software for predicting the transmission error of meshing parallel-axis and bevel gear pairs. He is also developing methods for carrying out structural dynamics calculations. Dr. Mark has developed fundamental definitions and interrelationships for the power spectra of nonstationary random processes, the Wigner-Ville distribution, and intensity modulated random processes.

Prior to his arrival at Penn State, Dr. Mark served as a principal scientist at Bolt, Beranek and Newman, Incorporated. He also served as an officer and physicist for the U. S. Air Force at the USAF Cambridge Research Laboratories. The author of over 20 archival journal articles, four book chapters, and approximately 100 contractor reports, Dr. Mark also co-authored the book "Random Vibration in Mechanical Systems," (Academic Press, 1963) with S. H. Crandell as senior author.

ARL and iMAST congratulates Dr. Mark on a job well done. Serving the U. S. Naval Service has been a proud tradition of Penn State's Applied Research Laboratory for over 56 years. ARL's iMAST program looks forward to continued support of the Department of the Navy as well as the Department of Defense.

Dr. Mark can be reached by phone at (814) 865-3922 or by e-mail at <wdm6@psu.edu>.

FOCUS ON MANUFACTURING SYSTEMS

Report Documentation Page

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IN THIS QUARTERLY

DIRECTOR'S CORNER

Mission Accomplished

In this issue, we announce Dr. William Mark's Navy Meritorious Civilian Service Award. As the principal investigator for gear metrology and performance prediction, Dr. Mark demonstrated "outstanding performance and exceptional dedication" as the lead analyst and designer of mechanical modifications that led to improved operational performance in a U.S. Navy submarine. For a ManTech investment of $800K, these modifications met a critical performance goal which provides a cost avoidance to the Navy of over $26M over a five-year period. Bill Mark is without peer. He continues his research, which applies to all gears, with the goal of improving gear life and reducing vibration. Bill Mark is a true American hero.

Simulation-Based Design (SBD) is featured in this issue. My vision of SBD is as a tool to optimize a design to a degree unachievable using previous design methods. Rather than evaluating a limited matrix of options, SBD can evaluate a whole range using operator-constrained inputs. Obviously, the design rules for the system must be accurately captured and understood. Hopefully, this effort will lead to unheard of efficiencies and cost savings. If you have any questions pertaining to this effort, please be sure to contact Mike Yukish.

Let me say a few words about technical assistants. TAs are the key to the successful implementation of a project. TAs are the necessary bridge between the developer and the program offices. The developer must have goals to shoot for that will meet program requirements. The TA, in conjunction with the program office, must translate the program requirements into metrics the developer can use to guide his/her project to completion. Metrics are the tool we use to evaluate the progress of a project. The developer, the TA, and the system command representative must agree to the metrics. One metric that all projects should have is a cost metric. This is necessary because if you conduct your research without an eye on affordability, you are likely to develop an unaffordable process.

We continue to conduct in-house quarterly reviews of our projects. Typically, these occur one month after a quarter closes. Participation by TAs is highly encouraged. It will go a long way in ensuring our projects stay on track. If attendance is unachievable, then concurrence in the presentation material will be appreciated. We encourage our TAs to take a more active role in the process. Our principal investigators should be maintaining close contact with respective TAs. PIs need to proactively keep TAs in the loop. For Navy ManTech to bear fruit, the entire process must continue to be an inclusive process. The rewards of that interaction will be measured through increased operational readiness within the U.S. Navy-Marine Corps team.

As always, we solicit your feedback. I encourage all interested readers to challenge us in our efforts along the way. Please note our points of contact and give them a call concerning any questions you have. Help us push ourselves to the edge of the envelop. Let us know how we can serve you. Beyond our project efforts, we also serve a dual role as an honest broker. For only the cost of a phone call, we are ready, willing, and able to provide you counsel on the various challenges you encounter day to day. If for some reason we cannot answer your questions, we will do our best to find someone within the Navy ManTech Program structure who can.

Bob Cook

MATERIALS PROCESSING TECHNOLOGIES · MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES · LASER PROCESSING TECHNOLOGIES · ADVANCED COMPOSITES MATERIALS TECHNOLOGIES · NAVY/MARINE CORPS REPAIR TECHNOLOGIES

Focus on Manufacturing Systems

Simulation-Based Design for Undersea Weapons

by Michael Yukish, Lorri Bennett, and Paul Kurtz

The Applied Research Laboratory of The Pennsylvania State University has developed a simulation-based design (SBD) capability for undersea weapons. The SBD system integrates tools for design creation, performance estimation, cost estimation, and persistent storage. An infrastructure for supporting SBD has been developed, based on the Common Object Request Broker Architecture (CORBA) and on the STEP EXPRESS information modeling standard. SBD systems for multiple weapons systems and subsystems have been fielded.

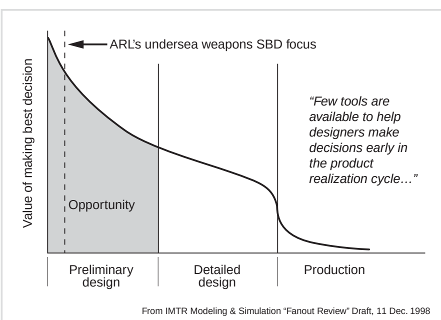


Figure 1. Value of decision at different stages of design process.

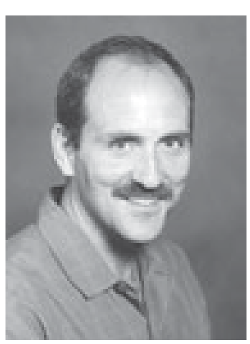
Figure 1 shows the relative impact of design decisions made at different points in the design process on the overall effectiveness of designs. From this figure, it is clear that decisions made early in the design process have effects measured in orders of magnitude, while decisions made later in the process serve only to perturb. Unfortunately, a minimum amount of information is available at this point in the process. Also, there are few tools available to support the design process.

The Office of Naval Research (ONR), one of the Laboratory's primary customers, is particularly interested in issues relating to technology transfer, i.e., in moving technologies from the laboratory to the fleet. Typically ONR will fund research and development in subsystem technologies, such as advanced thermal power sources or new signal processing technologies. But the technologies themselves are not the goal. The goal is to improve existing weapons systems and to develop new ones that provide our war fighters with an advantage. With this in mind, the following precepts define the capabilities that a simulation-based design system for conceptual design support must have:

- Subsystem technologies cannot be evaluated in isolation; they must considered within the context of the enveloping weapons systems.
- Evaluation of systems must take place in the context of specified missions and tactics.
- Performance cannot, in most cases, be evaluated in closed form; simulations must be used to determine a performance measure.

ARL has now developed the tools and techniques to support the early, conceptual stages of the design process for undersea weapons. When fully integrated, the tools form a simulation-based design system. Using this system, we can capture basic design rules for new technologies, rapidly develop new conceptual designs based on the technologies, evaluate them for cost and performance, and store the designs for later retrieval. While developed with a particular target domain, the tools and techniques have applicability to other complex systems, such as aircraft, missiles, and ships.

Figure 2 shows an example of how SBD can support the design of torpedoes. A user can specify the desired overall attributes (e.g. speed, depth, and range) of a torpedo together with different technology choices for the subsystems of the torpedo. The SBD system will generate a *virtual prototype* of a torpedo satisfying the desired functional characteristics while using the chosen technologies, or will tell the user that the design is not realizable. A virtual prototype at this early conceptual stage consists of data needed to drive the performance analysis tools, data to drive the cost estimating tools, and solid geometry at a low level of detail, showing the relative sizes and placements of the subsystems and components. At this point, the virtual torpedo can be subject to various cost and performance analyses and the determination of cost-effectiveness trades. In essence, the SBD system enables extremely fast analysis of alternative (AOA) exercises. Table 1 shows some results of exercising an SBD system for 6.25" dia. undersea vehicles. Between the four designs, power type and vehicle speed are varied. The first



PROFILE

Mike Yukish is Head of the Manufacturing Product and Process Design Department at ARL Penn State. He has been employed as a Research Assistant at ARL since 1993. Mr. Yukish is the leader of the simulation-based design effort in the Manufacturing Systems Division, and is principal investigator for ARL's undersea weapons design and optimization task. Mr. Yukish received a B.S. in Physics from Old Dominion University in 1983, and an M.S. in Mechanical Engineering from Penn State in 1997. He is currently completing requirements for a Ph.D. in Mechanical Engineering. Mr. Yukish, a Commander in the U. S. Naval Reserve, served as a Naval Aviator while on active duty prior to joining ARL. He can be reached at (814) 863-7143 or by e-mail at <may106@psu.edu>.

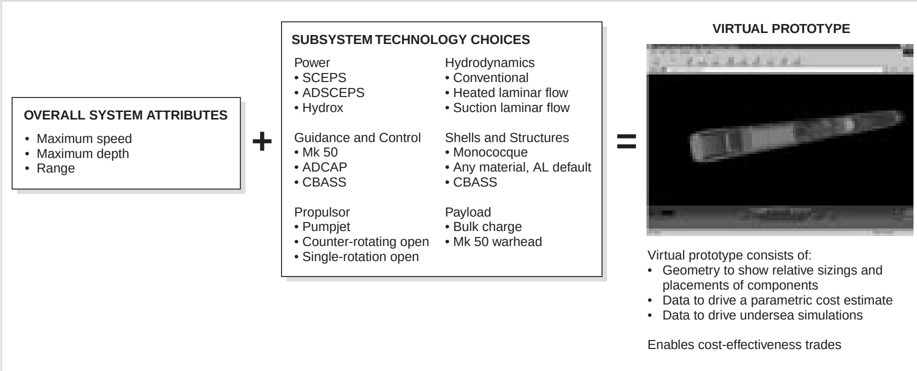


Figure 2. Conceptual design of a torpedo.

and the third vehicle have the same speed and range, but the third vehicle uses a HYDROX propulsion system. This system is smaller for the same total energy and allows for a larger warhead, resulting in a possible improvement in effectiveness. Offsetting the larger warhead is the higher cost of the HYDROX over SCEPS. By integrating the design rules, undersea simulations, and cost estimating, an SBD system enables quick tradeoffs of technologies.

Table 1. Design of a cost comparison of different 6.25" dia. vehicle prototypes.

Vehicle speed	60	55	60	55
Propulsion length	37	37	29	37
Power type	SCEPS	SCEPS	HYDROX	Electric-ALAGO
Endurance	1971	2660	1971	626.3
Warhead length	34.5	34.5	42.42	34.5
Warhead weight	64	64	79.09	64
Vehicle weight	210.3	206.7	215.3	213.5
UPC ($K)	181.1	177.9	263.8	212.3
Development ($M)	7.53	7.47	8.35	7.91
Production ($M)	18.11	17.79	26.38	21.23
Total cost ($M)	25.65	25.26	34.73	29.13

Implementation

ARL has had many years of experience with design automation and undersea simulation prior to this SBD effort. For example, the Generic Vehicle Configuration Model (GVCM), used for capturing rules for conceptual design of torpedoes and the progenitor of our current SBD system, was developed in the late 1970s. The Technical Requirements Model (TRM), is a legacy suite of undersea simulations developed with many man-years of effort, and it is still evolving today. The key has proved to be in the integration of the codes.

Our initial efforts at developing an SBD capability for torpedoes showed that, before the torpedo domain-specific rules and analyses could be implemented, a difficult information systems problem had to be solved. A critical characteristic of the design problem is that the experts in the process are distributed over the enterprise geographically, their computer codes vary from custom developed FORTRAN to Commercial Off The Shelf applications, and they are running on many different operating systems from VAX VMS to Windows NT. A key goal from the beginning was to use the expert's own tools, rather than forcing each expert to adopt a new single system. To support the goals above, the SBD system must have the following features:

- *Simple and robust structure* – The SBD system will be implemented by engineers, not computer scientists. Its architecture needed to be designed accordingly.
- *Based on an extensible architecture* – The structure of the SBD system should highly modular, to support reuse and ease integration.
- *Deployed over a heterogeneous computing environment* – Domain experts develop their services on their computing platform, at their sites, under their control.
- *Technology update/insertion* – The impact of a new technology insertion must be minimized, a goal best served by a modular structure.
- *Support hierarchy* – Design teams are typically composed of part-whole hierarchies that mirror the natural physical breakdown structure of the weapon.

To satisfy the requirements above, we developed the *rptide architecture* for implementing SBD systems. The architecture defines the four basic components of an SBD system; Design Servers, Analysis Agents, Repository, and Prototype. The Design Server is where the rules for conceptual design are captured. It creates virtual prototypes based on desired function. Analysis Agents evaluate designs for various cost and performance metrics. The Repository and Prototype provide supporting services for storing and retrieving designs and related analyses. Tying all of the components together is a Graphical User Interface, (GUI), that can be used to access each of the components. An example of an instantiation of an SBD architecture is Figure 3. Note the hierarchy of Design Servers, mirroring the Work Breakdown Structure of the undersea weapon. The Design Server and the Analysis Agent are the keys to the SBD systems, and are described below.

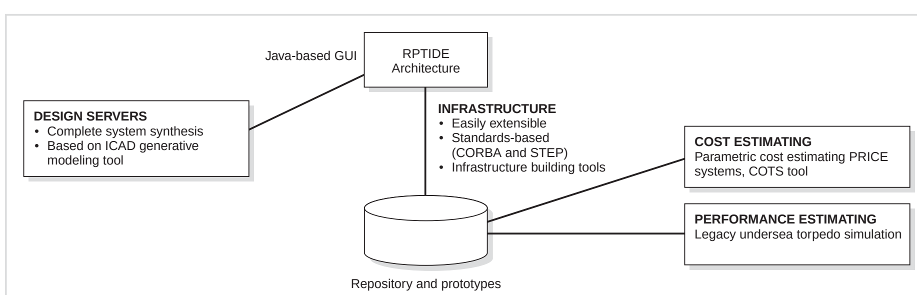


Figure 3. SBD system for torpedoes.

Interoperability

The architecture provides the necessary interoperability between components, operating systems, and networks. Interoperability naturally partitions into three levels: physical access, middleware, and semantics. Each deals with a different layer of abstraction.

Physical access concerns the physical medium (e.g., the Internet) that interconnects the nodes of the system, as well as security issues such as secure nets or encryption devices. Currently we are using the Internet as the physical network and planning to use encryption devices to create virtual subnets.

Middleware hides the heterogeneous, distributed nature of the SBD system, provides a uniform method of interacting with a broad variety of services, and adds services such as automatic application start-up and name and server directories. CORBA is being used together with the IIOP protocol for the middleware layer. In particular, the Design Servers, Analysis Agents, and Prototypes are all implemented as CORBA objects. An additional CORBA object, the Repository, is used to control a collection of Prototypes.

Semantics involves ensuring that each node in the SBD system shares a common vocabulary and method of interaction. Defining a set of base classes for Design Servers, Analysis Agents, Prototypes, and Repositories enforces SBD semantics for interoperation. The base classes set the minimum functionality for each object type and are sufficient for the SBD system.

Data semantics are ensured by defining *information models* for each system and subsystem and their related technologies. The information modeling method is derived from the STEP (Standards for Exchange of Product data) international standard.

The *information model* documents, in a manner that is both human and machine readable, the design data necessary to define an instance of the technology. This documentation is achieved by using the EXPRESS data specification language, part of the STEP

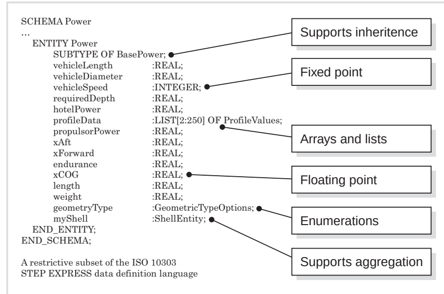


Figure 4. Simple information model for a power section.

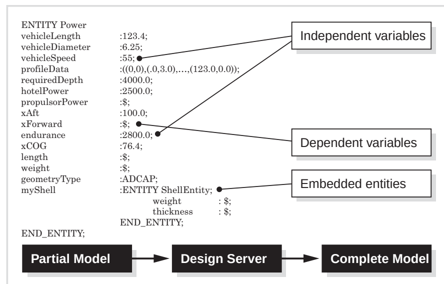


Figure 5. Clear text encoding for a power section.

standard. Along with being human and machine readable, EXPRESS supports the object-oriented structures of inheritance and aggregation.

Given that the purpose of a designer is to translate *function* and *constraints* into *form*, design data is defined as all required functions and constraints of the design, along with the design's form. Cost data and performance data are not part of the design information model. Separate information models are developed for them. An example of an information model is Figure 4.

Supporting the information model are rules for implementing a *clear text encoding* of an instance of the information model. The clear text encoding is based on ASCII text, and is both human readable and machine interpretable. The clear text encoding standard adopted for this project differs from the one defined by STEP. All passing of models between servers is via the clear text encoding. While this greatly increases the amount of data to be passed as compared to binary formats, it also simplifies the debugging process and enhances flexibility. An example is Figure 5.

Design Server

The Design Server is a CORBA interface that translates partial designs of a particular technology into complete designs (see Figure 6). Some examples are servers for shaped charge warhead technology, ADSCEPS power section technology, V-8 engine technology, and acoustic transducer technology. A design is defined as all data necessary to form a complete description of the artifact, to include input parameters such as required function and design constraints, descriptive data such as Bill of Materials, and solid geometry.

All instances of Design Servers inherit from the Base Design Server class. Every Design Server can supply an *information model* and a *constraint map* to its clients, on demand. The information model formally defines the data requirements for a particular design. The constraint map specifies the different possibilities of data that the client may provide as a partial model that the Design Server can successfully handle in constructing a complete model, Figure 7. By providing an information model and a constraint map at runtime, a client can find a Design Server, discover what service it provides, and dynamically develop a request for design services.

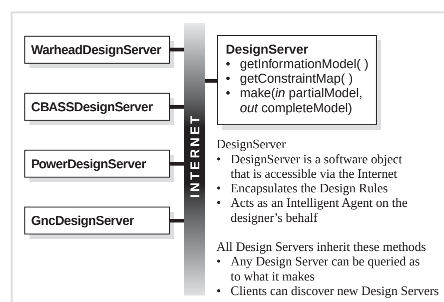


Figure 6. Design server implementation.

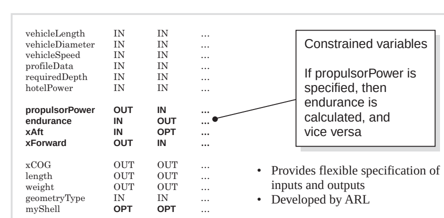


Figure 7. Constraint map for power section.

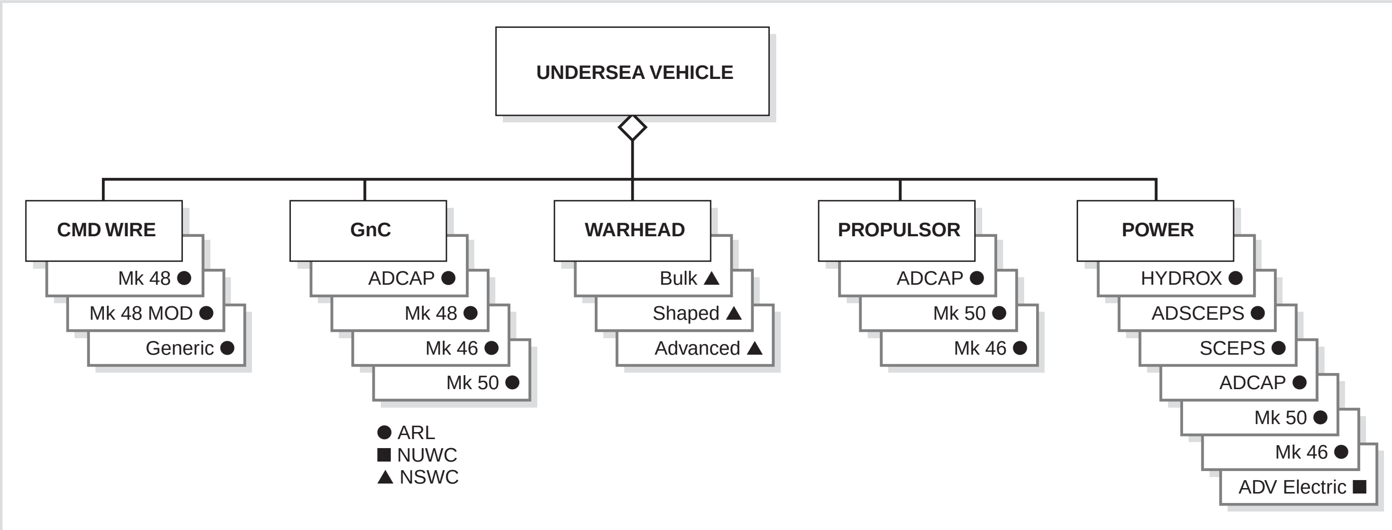


Figure 8. Hierarchy of design servers.

The Design Servers can also form a hierarchy of aggregation, where a Parent Design Server calls on a number of Child Design Servers. By decomposing the design process into a hierarchy, the impact of introducing new Design Servers is minimized. An example is Figure 8.

Analysis Agents

For each design instance, or virtual prototype, there can be many analyses. For example, a cost analysis for a weapon would differ greatly based on the size of a production run, production start date, and expected maintenance plan. An undersea simulation would need design information of a weapon, but also scenario-specific information such as target type and bathymetry to estimate performance. Therefore, Analysis Agents are defined to take as their input completed designs and a *partial analysis,* and to return a complete analysis. In a manner similar to Design Servers, the Analysis Agents provide information models and constraint maps for their analyses

Example

Thermal Power Design Server

Figure 9 shows the level of detail generated by a subsystem Design Server, in this case for a Thermal Power Source. The geometry shows the oxidant tank, boiler, and engine. The Work Breakdown Structure of the Power Source is visible on the left. Figure 10 shows how the geometry scales in response to differing functional requirements. The increase in desired range directly translates into an increase in boiler size and oxidant size. The Design Server is implemented using ICAD, a knowledge-based engineering tool that combines a LISP-based language with the parasolids solid modeling kernel. The Design Server is hosted on a UNIX platform.

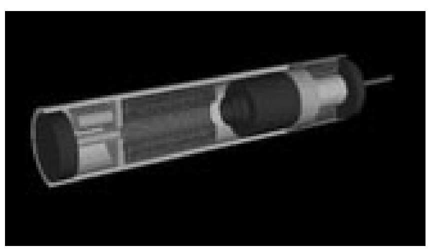


Figure 9. Level of detail generated by a Thermal Power design server.

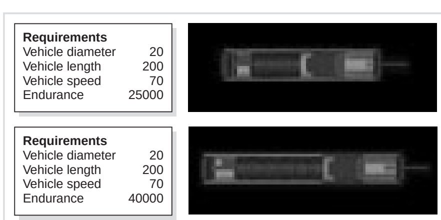


Figure 10. Comparison of two designs of thermal power design server with different endurance requirements.

Summary

ARL has developed an architecture for implementing SBD systems for undersea weapons systems, and has deployed a number of systems for different weapons systems. Our work has focused on the conceptual design stage, and provides rapid, relatively accurate estimates of reliability, geometry, cost, and performance of new technologies.

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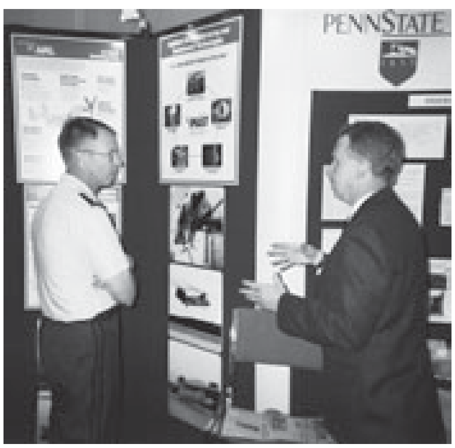
Showcase For Commerce

ARL's Bob Cook (left) and Tom Donnellan (right) chat with U.S. Congressman John Murtha (12th District, Pennsylvania) during his stop by iMAST's exhibit booth at the Johnstown Showcase for Commerce forum.

iMAST recently participated in the Johnstown (PA) Showcase for Commerce forum in Cambria County, Pennsylvania. The showcase provided an opportunity for business, government, and research organizations alike to showcase advanced technology efforts being developed throughout the local region. Industry support by United Defense, Raytheon, DRS Technologies, General Dynamics and The Boeing Company attest to the quality level of particpation. Forums like Johnstown's Showcase for Commerce aid technological innovation efforts by bringing together the necessary ingredients to transfer technology into both civilian and DoD manufacturing sectors. Opportunities like this showcase provide smaller organizations an excellent chance to interface with key players in the research and developmental world, as well as manufacturers and DoD customers. In many cases, out-of-the-box thinking emerges as dialog develops between researchers, manufacturers and customers. The annual Johnstown Showcase for Commerce is scheduled again for next June. Check our calendar of events in future iMAST newsletters for more information.

AHS Forum 57



Dr. Tom Donnellan, Associate Director, ARL Materials and Manufacturing, discusses the iMAST program with MGen Joseph Bergantz, USA at Penn State's AHS exhibit booth. General Bergantz is the PEO (Aviation) for the U.S. Army.

The 57th annual American Helicopter Society Forum was recently held in Washington, D.C. iMAST and the Penn State Rotorcraft Technology Center of Excellence participated together in great force once again. This year's theme, "Expanding VSTOL Roles and Missions" drew large industry participation and guest speakers from throughout the United States. The forum provided an excellent opportunity to communicate recent developments in the advancement and application of vertical flight technology. iMAST project leaders made several presentations. These presentations included: Dr. Jogender Singh discussing "Functional Graded Thermal Barrier Coatings for Turbine Components;" Dr. Tim Eden presented "Spray Formed Aluminum Alloys for Rotorcraft Application;" Ms. Lorri Bennett talked about "Rotorcraft Conceptional Design Environment;" and Mr. Ted Reutzel reviewed his program effort on "Lightweight Laser Welded Stiffened Structures" applications for the MV-22.

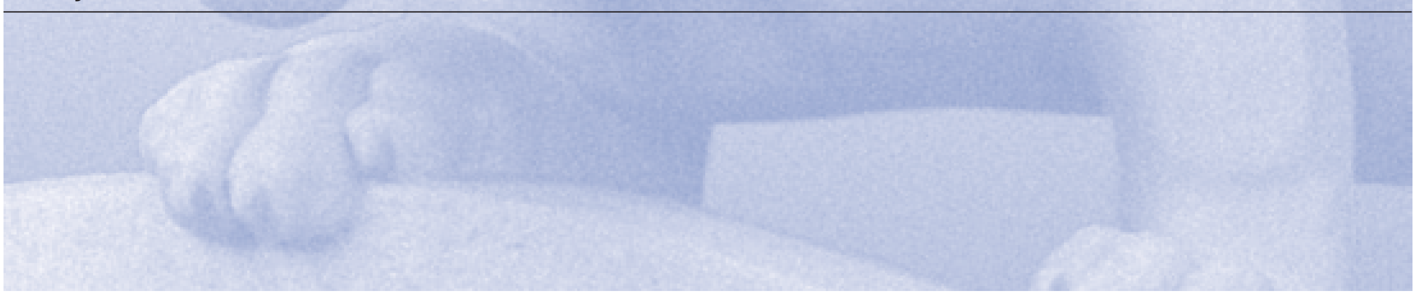
AHS Forum 58 will be held in Montreal, Canada next year (11-13 June 2002). The theme for that forum will be "Vertical Flight Technology: Building a Global Consensus." AHS Forum 55 was held in Montreal two years ago to a very large government and industry contingency. For more information about AHS, call (703) 684-6777, or write Mr. Rhett Flater, Executive Director AHS, 217 N. Washington Street, Alexandria, VA 22314. You can also send an e-mail to <ahs703@aol.com>. Also check their web site out at: <http://www.vtol.org>.

Looking for Web in All the Right Places

We need your help! iMAST is currently in the process of updating and improving our web site. Please take a moment to visit our site at <http://www.arl.psu.edu/areas/imast/imast.html>. After you view it, we would greatly appreciate your feedback on how we might improve it to better serve you, our customer. Don't be afraid to help us think outside of the proverbial box. We believe the World Wide Web is an excellent technology transfer and communications tool, when used in conjunction with sound management practices. If you have a question, criticism, or suggestion, please contact the institute administrator, Greg Johnson, at (814) 865-8207, or by e-mail at <gjj1@psu.edu>.

CALENDAR OF EVENTS

13–15 Aug	Second Annual ONR Naval-Industry R&D Conference	★★★★★ *visit the iMAST booth*	Washington, D.C.
20–24 Aug	Penn State Rotary Wing Technology Short Course		University Park, PA
5–6 Sep	Shipbuilding Technologies 2001		Biloxi, MS
10–13 Sep	NDIA Joint Undersea Warfare Technology Conference		Groton, CT
18–20 Sep	Marine Corps League Expo	★★★★★ *visit the iMAST booth*	Quantico, VA
24–26 Sep	NDIA Combat Vehicles Conference		Panama City, FL
24–26 Sep	Combat Vehicles Conference		Ft. Knox, KY
TBA	AUSA Expo		Washington, D.C.
7–10 Oct	AGMA Gear Expo		Detroit, MI
29 Oct–1 Nov	5th Annual DoD Maintenance Symposium		Kansas City, MO
29 Oct–1 Nov	NDIA Expeditionary Warfare Conference		Panama City, FL
26–29 Nov	Defense Manufacturing Conference	★★★★★ *visit the iMAST booth*	Las Vegas, NV
26–28 Mar 2002	Navy League Sea-Air-Space Expo		Washington, D.C.
3–4 April	Tech Trends 2002		Baltimore, MD
11–13 Jun	AHS Forum 58	★★★★★ *visit the iMAST booth*	Montreal, Canada



Quotable

"If you think America still has a vast military-industrial complex consuming much of the [U.S.] economy, think again. The entire defense industry now claims less than 1 percent of gross domestic product. Lexington Institute estimates that when all the numbers are in, the combined military sales of the nation's top 10 defense contractors will total less than half of WalMart's [WalMart Stores, Inc. retail] revenues."

—Loren B. Thompson, CEO Lexington Institute

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